Engine Icing Simulation and Detection

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Overview

- Problem of Engine Power Loss
- Engine Rollback
- Modeling Engine Icing Effects
- Simulation of Engine Rollback
- Icing/Engine Control System Interaction
- Detection of Ice Accretion
- Mitigation of Engine Rollback
- Conclusions

Problem of Engine Power Loss

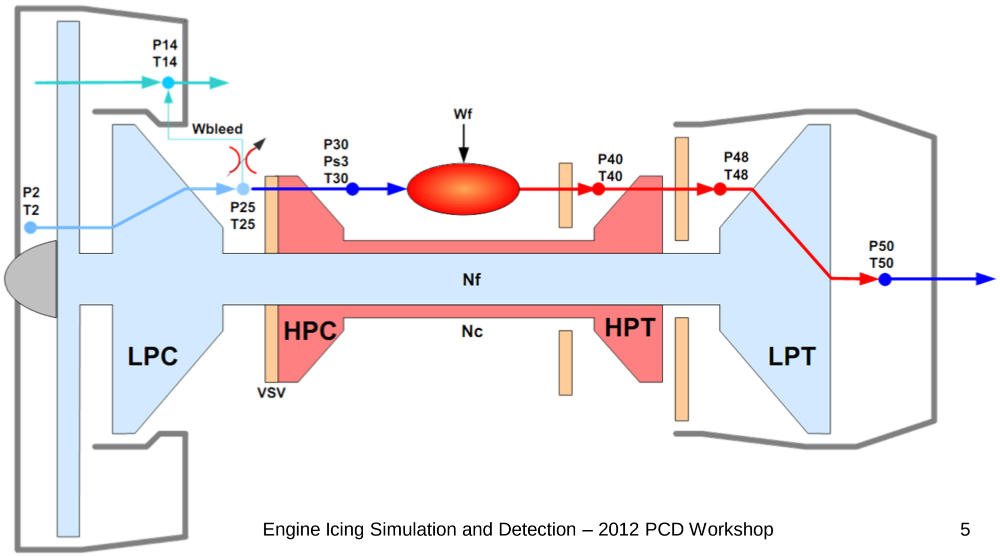
- More than 200 power loss events reported in last 20 years in High Ice Water Content conditions
  - Temporary or sustained power loss, uncontrollability, engine shutdown
- Many possible causes:
  - Compressor surge
  - Flame-out due to combustor ice ingestion
  - Damage due to ice shedding
  - Sensor Icing
  - Engine Rollback

Engine Rollback

- Associated with ice accretion in compressors
- Symptoms:
  - Uncommanded thrust reduction
  - Decrease in fan shaft speed
  - Increase in turbine temperature
  - Increasing the throttle does not produce additional thrust
- To study rollback, we must be able to realistically simulate it

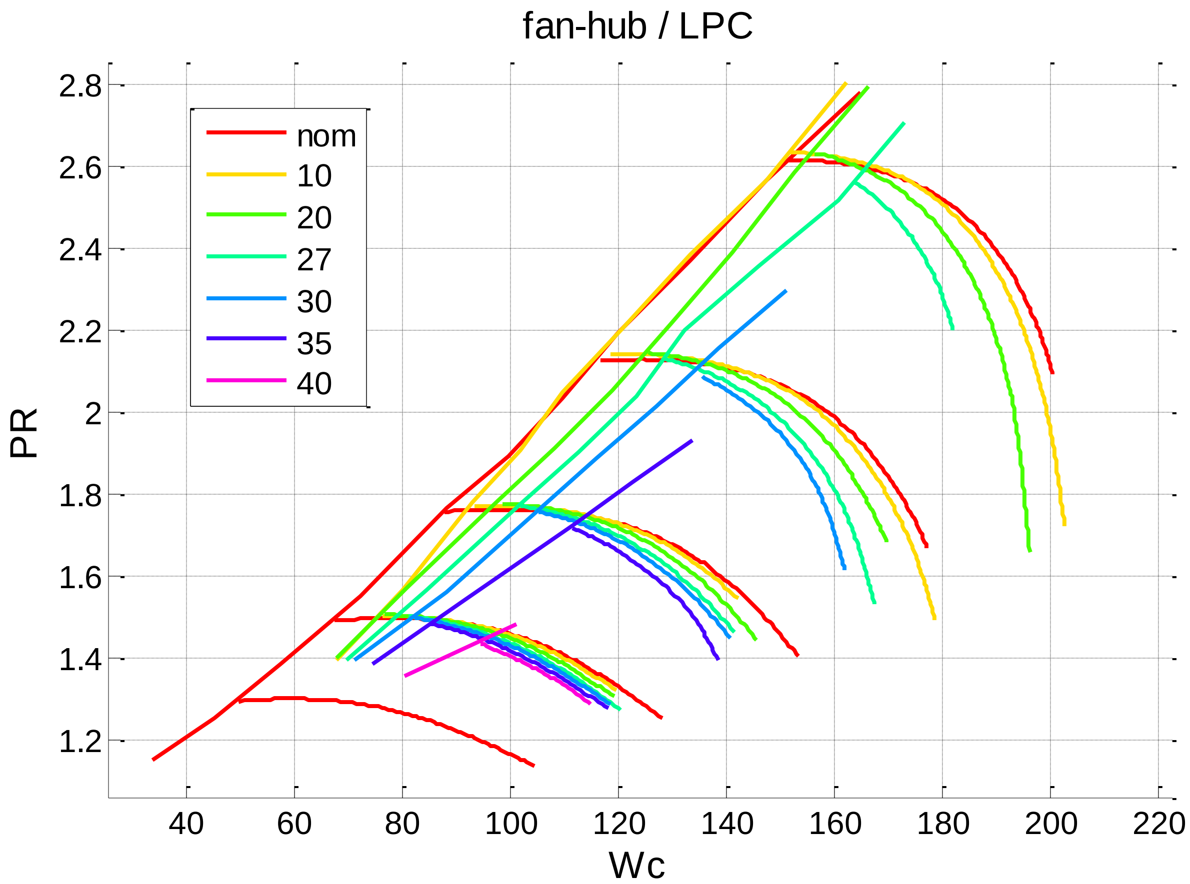
Modeling of Engine Icing Effects

- C-MAPSS40k engine simulation
  - Commercial 40,000lbf thrust, high-bypass turbofan engine
  - Physics-based model
  - Realistic engine control system
  - Written in MATLAB/Simulink
  - Modular design



Modeling of Engine Icing Effects

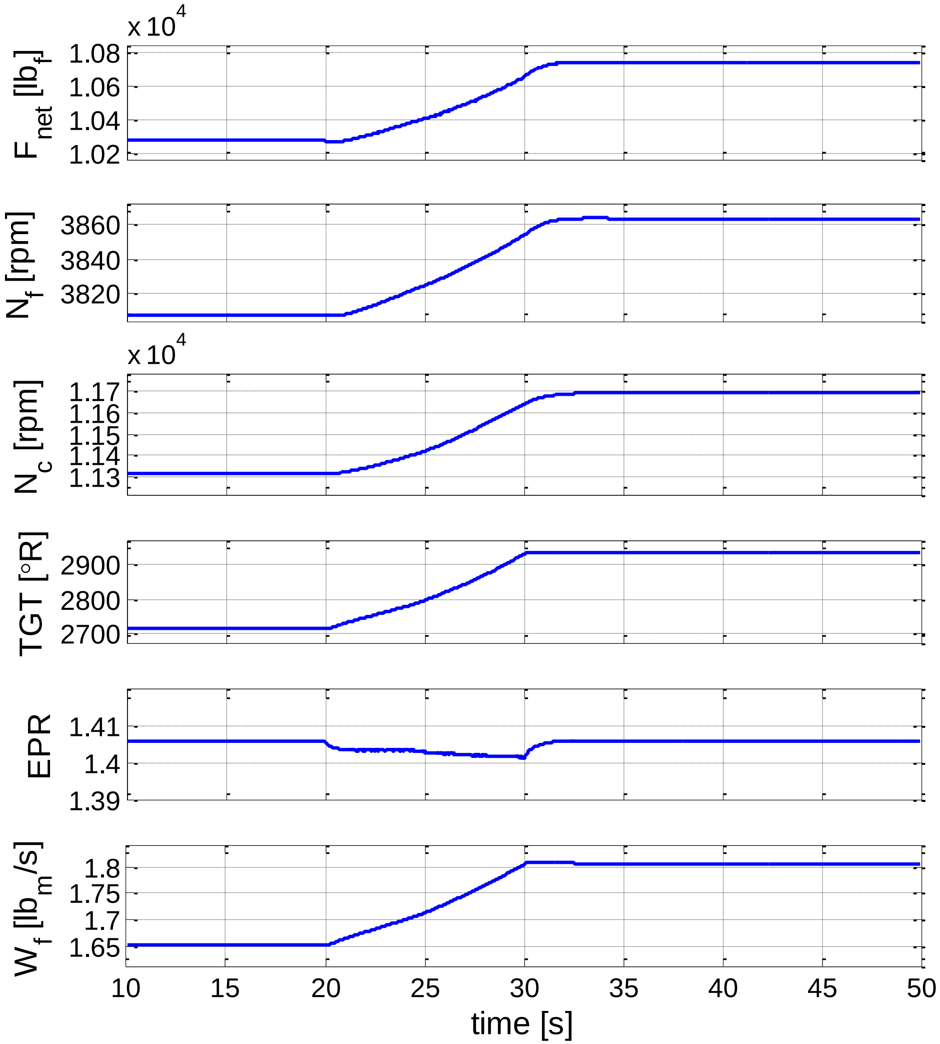
- LPC Compressor maps with various quantities of ice blockage in the 2nd row stator
- Integrated into C-MAPSS40k
  - Linear interpolation between maps



- Decrease in Surge Line
- Speed Lines shift to the left

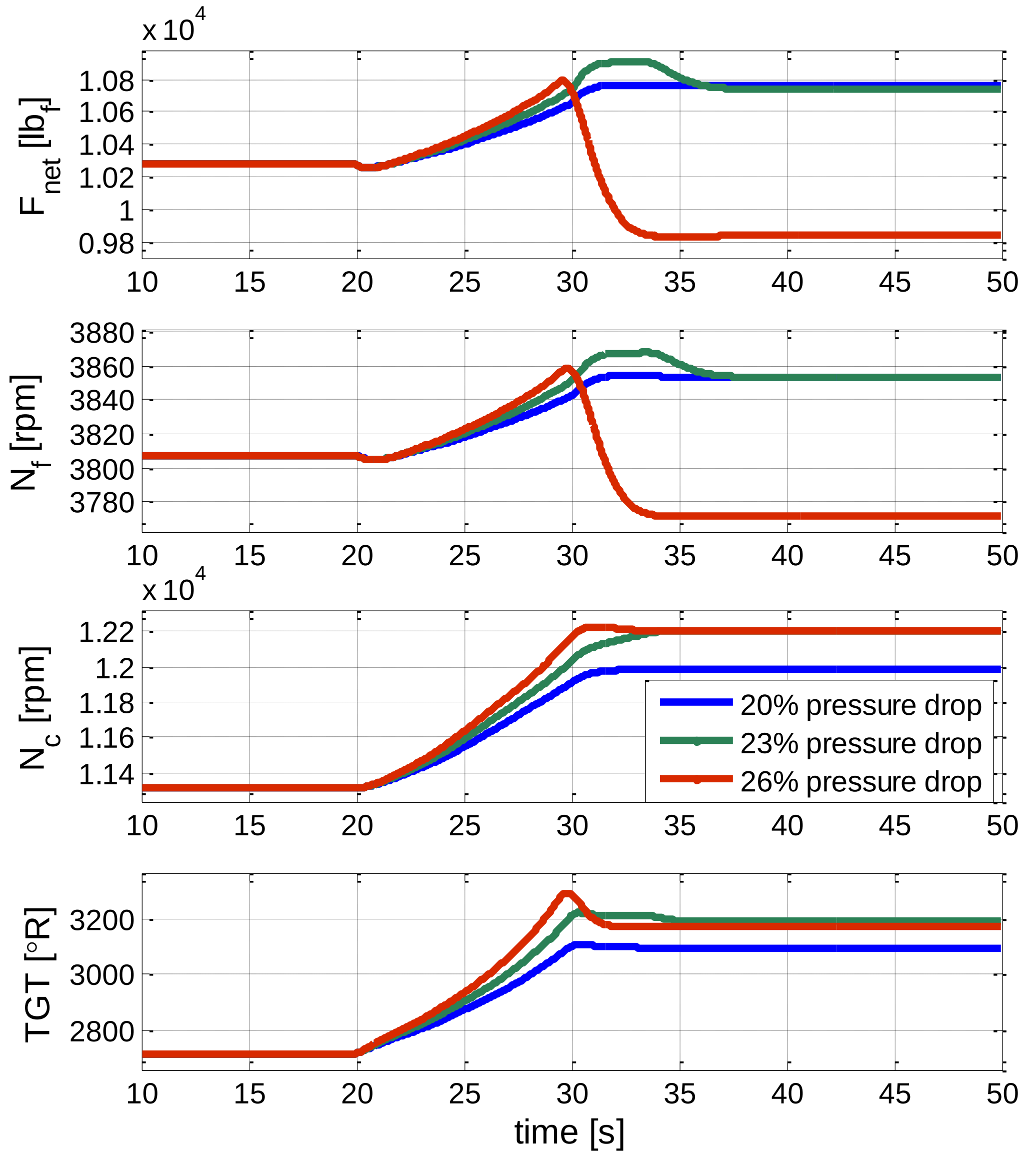
Simulation of Engine Rollback

- Impact of Engine Icing
  - Start from nominal conditions and increase the blockage level
  - Move from nominal LPC map to 20% blocked map
- Effect:
  - Drop in EPR -> increase in fuel flow rate and thus increase in Fnet, Nf, Nc, TGT
  - No Rollback event



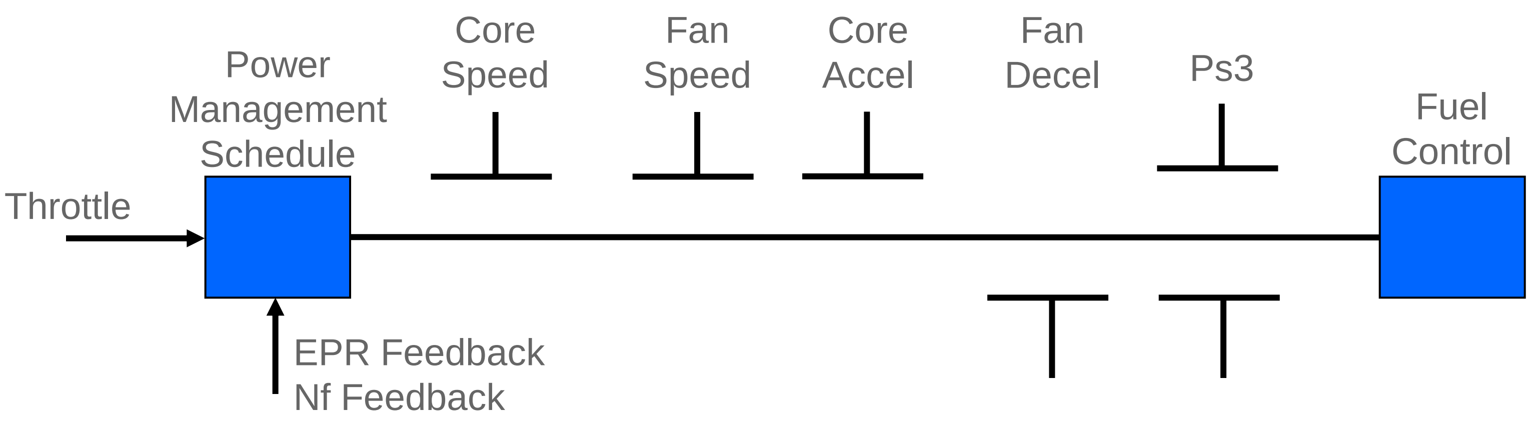
Simulation of Engine Rollback

- As blockage increases, eventually a rollback occurs
- Decrease in thrust
- Decrease in fan speed
- Increase in TGT



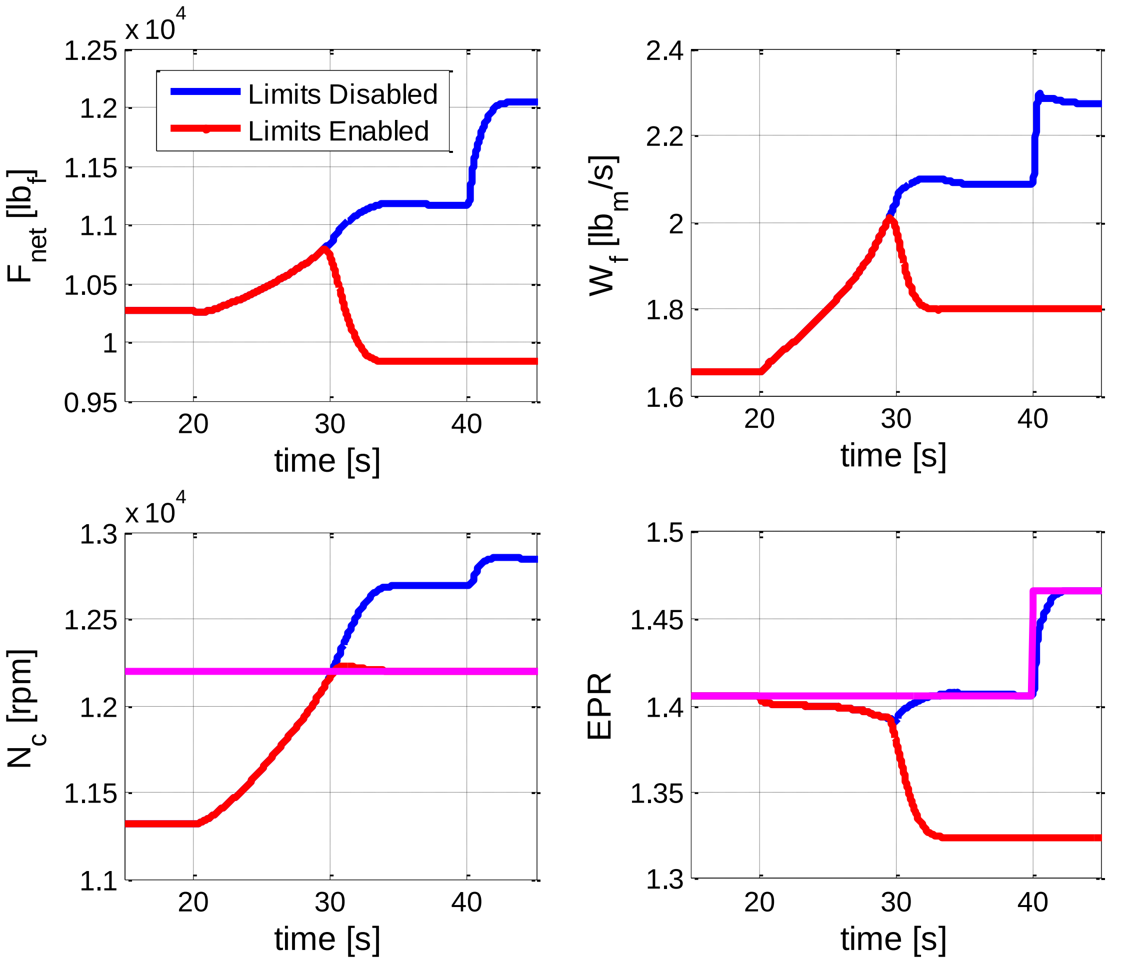
Engine Control System

- Power Management
  - Responsible for holding current power level (EPR or Nf)
- Protection Logic
  - Responsible for ensuring safe operation
  - Adjusts Fuel Flow to ensure limits are observed



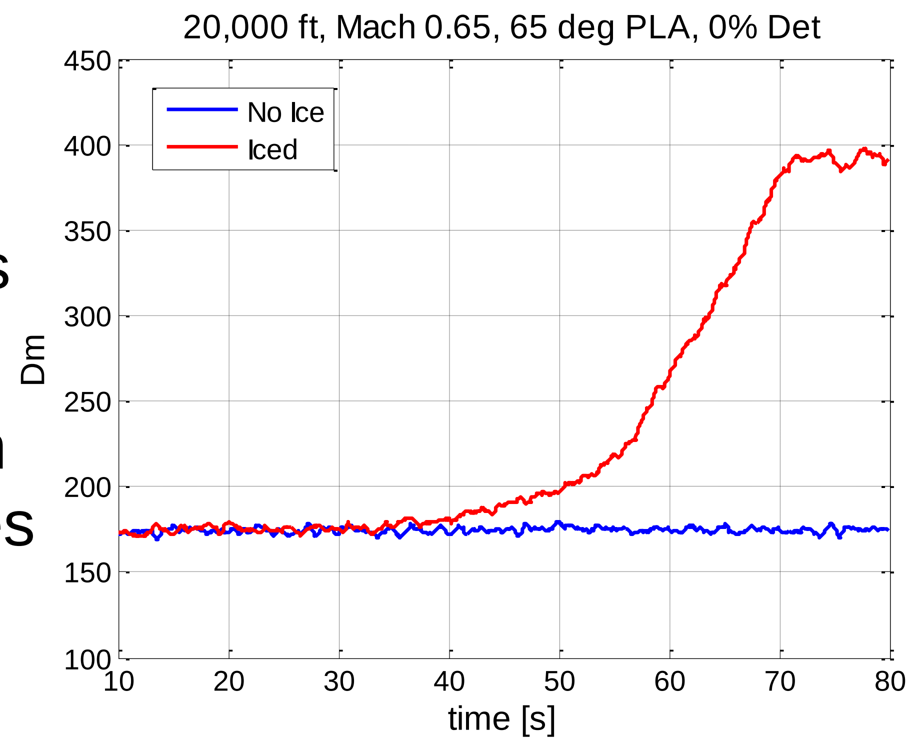
Controller Response To Icing

- Core speed limit prevents fuel flow rate from continuing to increase
- With limits disabled there is no rollback (but engine is at higher risk of failure due to high core speed)



Detection of Engine Icing

- Typically 5 – 7 sensors present in an engine
- Icing introduces a fault signature that can be detected with these sensors
- Use a Distance Measure (Dm) to determine deviation from expected sensor values
- Operate in conjunction with airframe devices to reduce chance of false-positive



- Developing a technique for full envelope detection

Mitigation of Engine Ice Accretion

- Ideally, completely avoid ice accretion
- If we can detect accretion can the engine controller act to mitigate the impact of the ice blockage?
- Potential mitigation strategies:
  - Operate actuators off-nominally to change operating point to either melt/prevent ice accretion or reduce chance of rollback
    - Close inter-compressor bleed valve
    - Move HPC inlet guide vanes off schedule
    - Use existing airframe integration in novel ways (e.g. customer bleed, power takeoffs)
  - Change shaft speed to cause ice to shed

Future Work

- Complete development of engine icing detection algorithm
- Test various mitigation techniques
  - Work with Turbomachinery and Icing branches at GRC to evaluate results and impact on ice accretion
- Validate models based on data from upcoming (FY13 & 14) engine icing flight tests and rig tests in GRC's Propulsion Systems Laboratory

Related NASA Publications:

- Jorgenson, P.C.E., Veres, J.P., May, R.D., Wright, W.B., "Engine Icing Modeling and Simulation (Part I): Ice Crystal Accretion on Compression System Components and Modeling its Effects on Engine Performance," 2011-38-0025, SAE International Conference on Aircraft and Engine Icing and Ground Deicing, Chicago, IL, Jun 13-17, 2011. doi:10.4271/2011-38-0025
- May, R.D., Guo, T-H., Veres J.P., Jorgenson, P.C.E., "Engine Icing Modeling and Simulation (Part 2): Performance Simulation of Engine Rollback Phenomena," 2011-38-0026, SAE International Conference on Aircraft and Engine Icing and Ground Deicing, Chicago, IL, Jun 13-17, 2011. doi:10.4271/2011-38-0026
- May, R.D., Simon, D.L., Guo, T.H., "Modeling and Detection of Ice Particle Accretion in Aircraft Engine Compression Systems," to be published at AIAA Atmospheric Flight Mechanics Conference, Minneapolis, Minnesota, August 13-16, 2012.

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